

Evaluation of Carbon Composite Overwrap Pressure Vessels Fabricated Using Ionic Liquid Epoxies Project

Center Innovation Fund: MSFC CIF Program | Space Technology Mission Directorate (STMD)



ABSTRACT

The intent of the work proposed here is to ascertain the viability of ionic liquid (IL) epoxy based carbon fiber composites for use as storage tanks at cryogenic temperatures. This IL epoxy has been *specifically* developed to address composite cryogenic tank challenges associated with achieving NASA's in-space propulsion and exploration goals. Our initial work showed that an unadulterated ionic liquid (IL) carbon-fiber composite exhibited improved properties over an optimized commercial product at cryogenic temperatures. Subsequent investigative work has significantly improved the IL epoxy and our first carbon-fiber Composite Overwrap Pressure Vessel (COPV) was successfully fabricated. Here additional COPVs, using a further improved IL epoxy, will be fabricated and pressure tested at cryogenic temperatures with the results rigorously analyzed. Investigation of the IL composite for lower pressure liner-less cryogenic tank applications will also be initiated. It is expected that the current Technology Readiness Level (TRL) will be raised from about TRL 3 to TRL 5 where unambiguous predictions for subsequent development/testing can be made.



Carbon Fiber-Overwrapped Pressure Vessels (COPV) Manufactured Using Commercial (left) and Ionic Liquid (right) Epoxies

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ANTICIPATED BENEFITS

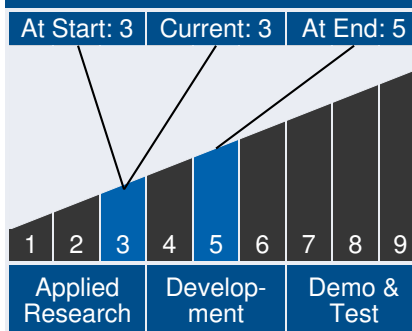
To other government agencies:

This effort will lead to composite cryotanks with improved strength and toughness which will enhance NASA's capabilities in launch propellant storage and in In-Space propellant storage.

To the commercial space industry:

This effort will lead to composite cryotanks with improved strength and toughness which will enhance capabilities of the commercial space industry in launch propellant storage and in In-Space propellant storage.

Technology Maturity



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DETAILED DESCRIPTION

In terms of "Innovation" this is a unique epoxy with unique properties, and NASA co-holds the patent. This epoxy is being exclusively formulated for cryogenic use. Utilizing storage tanks fabricated from fiber reinforced polymeric composites for storing cryogenic fluids such as liquid oxygen and liquid hydrogen under pressure is of great interest to NASA. In particular, their high strength to weight ratio gives them a clear advantage over strictly aluminum alloy components; a 20-40% weight reduction can also be expected. Unfortunately such composites, especially at cryogenic temperatures, develop stiffness that diminishes the desired toughness; this promotes delamination and crack growth which leads to leaking of the fuel component; this detriment is exacerbated if the component is cycled between room and cryogenic temperatures. The work proposed here intends to eliminate that concern by utilizing a unique, and patented, ionic liquid (IL) epoxy. Our novel, to date, results supporting that supposition include:

- A viable means to synthesize high-quality ionic liquid epoxy monomer has been established.
- Nano-scale Core-Shell-Rubber (CSR) particles designed to toughen polymers have been successfully and uniformly incorporated into the epoxy matrix.
- Shock cycling of the epoxy between room (RT) and Liquid Nitrogen (LN2) temperatures, with and without CSR, does not appreciably affect the fracture energy at RT establishing that micro-cracking does not develop in the samples.
- Testing shows that adding CSR particles improve toughness and strength at RT and LN2 temperatures.
- Measurements of the epoxy Coefficient of Thermal Expansion from cryogenic to room temperature is very favorable at 35 ppm

Management Team

Program Manager:

- John Falker

Project Manager:

- Andrew Keys

Principal Investigator:

- Richard Grugel

Co-Investigators:

- Chad Hastings
- William Kaukler
- Ellen Rabenberg

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which places it amongst the lowest of the common polymers.

- CSR increased the glass transition temperature (0% CSR = 61.5°; 8.8% CSR = 95.5°C) allowing a higher working range.
- Carbon-fiber test articles utilizing CSR containing epoxy have been made and show no cracking or delamination when repeatedly cycled in LN2.

Relevant test results show improvements over commercial products at both room and LN2 temperatures. Slight additions of CSR significantly increases the impact toughness which appears maximized near an 8.8% addition. Considerable improvements were also noted here at both room and LN2 temperatures. It was also noted that shocking the samples between room and LN2 temperatures, up to 10 times before testing, had no obvious effect in diminishing properties, i.e. no induced micro-cracking.

Earlier, it had been shown that a carbon fiber composite cylinder fabricated with the ionic liquid epoxy performed better at room and LN2 temperatures than the commercially used Hexcel®. We have since successfully made some carbon fiber layups utilizing CSR containing epoxy for preliminary examination and testing. Composite integrity was maintained on these layups with no separation, delamination, or cracking.

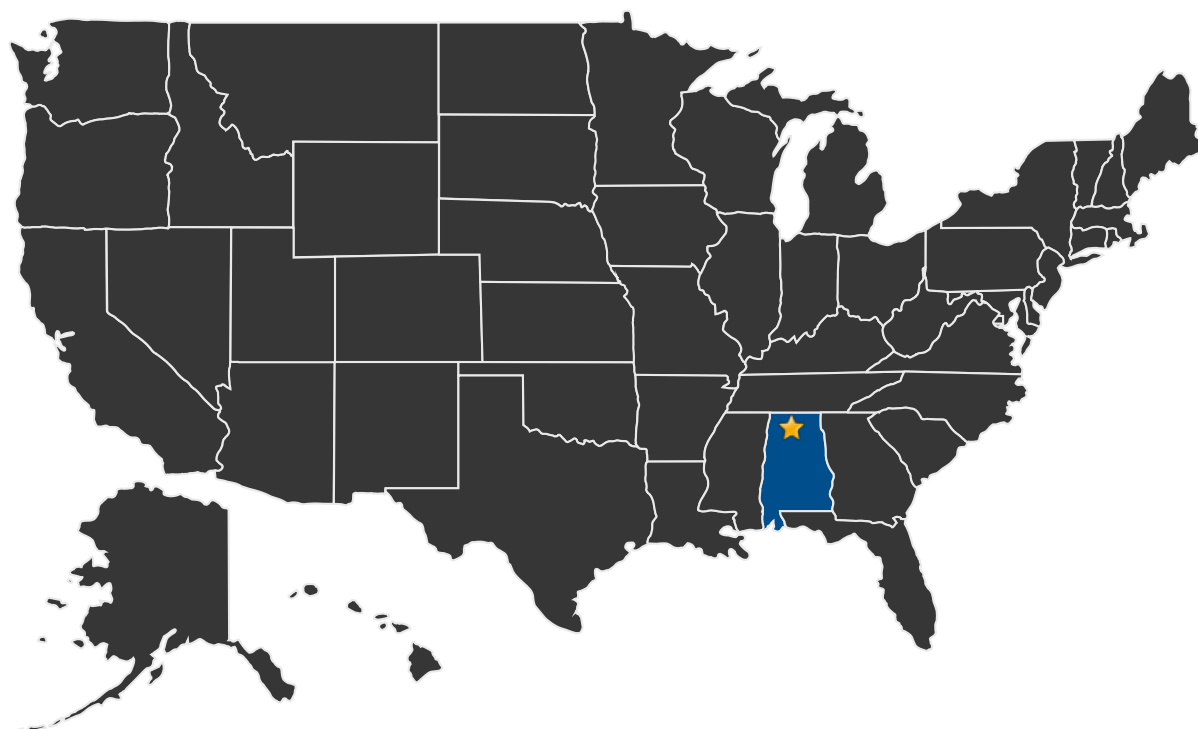
Finally, ionic liquids have a number of additional advantages as a base for epoxy resins. Their extremely low vapor pressures, good temperature stability, and low flammability further enhance their use for NASA deep space, cryogenic, applications. They have a comparatively "greener" manufacturing process than their counterparts. Low permeability to hydrogen, and trivial moisture uptake after several days of submersion in salt water was also established. The epoxy has also demonstrated strong binding to aluminum. In short, ionic liquid based epoxies and composites are ideally suited to meet challenges associated with achieving NASA's space exploration goals.

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U.S. LOCATIONS WORKING ON THIS PROJECT



■ U.S. States With Work ★ **Lead Center:**
Marshall Space Flight Center

Other Organizations Performing Work:

- AZ Technology Inc (Huntsville, AL)

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DETAILS FOR TECHNOLOGY 1

Technology Title

Carbon-fiber Composite Overwrapped Pressure Vessel

Technology Description

This technology is categorized as a hardware component or part for ground support or mission operations

Specifically, this technology involves the use of ionic liquids as the epoxy for carbon-fiber composite overwrapped pressure vessels as opposed to other, commercial epoxies.

Capabilities Provided

The use of ionic liquids as the basis for an epoxy for this application has shown improved properties over commercial products at cryogenic temperatures.

Potential Applications

The primary application for this technology is space-based storage vessels for propellants and other materials. This technology could support NASA's orbiting fuel depot, the Cryogenic Propellant Storage and Transfer (CPST) project, the Space Launch System (SLS) and its cryogenic propulsive stage.